INTERACTION BETWEEN SURFACE GRAVITY WAVES AND NEAR SURFACE ATMOSPHERIC TURBULENCE

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LONG-TERM GOAL

The long-term goal of this study is to clarify the detailed physical mechanism of the interaction between surface gravity waves and near surface atmospheric turbulence, and to improve our predictive capability of the momentum and energy transfer between the atmosphere and the ocean.

SCIENTIFIC OBJECTIVES

The specific objectives of this project are to study a) how energy and momentum are transferred from turbulent wind to surface gravity waves, b) how surface gravity waves modify the structure of near-surface turbulence, and c) how these interaction processes are influenced by the directionality of wind and waves.

APPROACH

Using existing experimental data from the MBL/ARI (RASEX and MBL West Coast), we examine the vertical structure of wind turbulence over gravity waves, namely the wave-induced pressure field, the wave-induced velocity field, and the wave-induced momentum flux, based on our similarity hypothesis [Hare at al., 1997]. In particular, we incorporate the analysis of directional surface wave spectra based on the Data Adaptive Spectral Estimator [Hanson et al., 1997] to address the directional effect of the coupled wind-wave processes. This is one the first opportunities to investigate detailed fluid mechanics which impacts the air-sea momentum flux and wave growth due to wind in a realistic ocean environment. We believe this is a significant step beyond the conventional "drag coefficients" analysis, which conceals many important dynamics of the wind wave interaction.

This is a close collaboration between myself and Jeffrey Hare at NOAA/ETL. While Jeff continues the similarity analysis for cases where wind and waves are aligned, I am mainly responsible for investigating other cases using the directional analysis. Other co-investigators of this project are James Edson (WHOI), Larry Mahrt (OSU), James Wilczak, Chris Fairall (NOAA/ETL), Carl Friehe (UC-Irvine), Jorgen Hojstrup (RISOE).

WORK COMPLETED

We have completed the data analysis from the RASEX when wind and waves are aligned, and

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published the results [Hare et al., 1997]. We have performed preliminary analyses using the open ocean data from the MBL West Coast Experiment as well as from the Coastal Ocean Probing Experiment (NOAA) in 1995. We have initiated investigation of the directional and nonlinear characteristics of surface wave fields from the RASEX and the MBL West Coast data.

RESULTS

Our similarity analyses of the RASEX data demonstrate that, when compared to theory, simple extrapolation of measurements of the wave-induced pressure field from a fixed height above the surface may contribute to the uncertainty of measured momentum fluxes. In addition, our similarity relationship for the wave-induced vertical velocity field yields results that are consistent with previous laboratory studies. This suggests that the similarity hypothesis may be valid over a reasonably wide range of wind and wave conditions, as long as waves are not too steep and are aligned with wind.

The same similarity analysis has been applied to the data obtained from the open ocean condition during the NOAA Coastal Ocean Probing Experiment. The results have been compared with those obtained from the RASEX data. The wave-induced pressure signal seems to be generally much weaker and behave quite differently in open ocean conditions. Consequently, the wave-induced momentum flux is estimated to be smaller over an open ocean than in a coastal area. The preliminary analysis of the MBL West Coast data, using the same similarity hypothesis, also indicates similar trends.

The linear analysis of wind-wave coupling is not likely to work well when waves are very steep or are breaking. Belcher and Vassilicos [1997] has proposed a model of equilibrium spectra of breaking waves. According to their model, when the ocean surface is covered by breaking waves, the frequency wave-height spectrum is determined by the dominant waves and their bound higher harmonics. Consequently, it does not contain any information about shorter waves. If this is the case, the linear analysis performed in the time domain (including our linear analysis between waves and wave-induced wind signals) may result in erroneous estimates of wave-induced momentum flux.

In order to address the directionality and the nonlinearity of the wind-wave coupling processes, we have developed an algorithm of estimating the frequency-wavenumber wave height spectrum, by extending the Data Adaptive Spectral Estimator developed by our group [Hanson et al., 1997]. Our original algorithm assumes that all waves propagate at their own phase speeds determined by the dispersion relation, and seeks the most likely direction in which waves propagate. With our revised algorithm, waves are allowed to propagate at all speeds, and estimations are made for both the most likely propagation direction and the most likely propagation speed. This allows us to study the detailed dispersion characteristics of wave components. In Figures 1 we show an example of the frequency-wavenumber spectrum along the mean wind direction obtained from the RASEX data. The spectrum up to twice the dominant frequency is consistent with the dispersion relation suggesting that these waves are mostly linear. At higher frequencies the spectral peak for a given frequency is observed at much lower wavenumbers than the dispersion relation. A result obtained from the MBL West Coast is shown in Figure 2. Now, the dispersion characteristics are

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Figure 1. Frequency spectrum (top) and frequency-wavenumber spectrum (bottom) of surface waves from RASEX. Along-wind direction. Solid line, dispersion relation; red dots, location of spectral peak at a given frequency.

significantly changed. Except near the dominant wave peak, the spectral peak at a given frequency is observed at lower wavenumbers than the dispersion relation throughout the observed frequency range. This result suggests that frequency wave spectra may indeed be dominated by steep dominant waves and their bound harmonics, in particular, in open ocean conditions.

IMPACT/APPLICATION

If the ocean wave frequency spectra are strongly influenced by the dominant waves and their harmonics, as predicted by the theory of Belcher and Vassilicos [1997], our linear study of the coupled air-sea systems, as well as any linear analyses based on the temporal wave height data, requires caution in interpreting the results.

TRANSITIONS

Our directional wave spectral analyses have been incorporated by other MBL/ARI investigators for the study of atmospheric turbulence in the wave boundary layer.

RELATED PROJECTS

We have been participating in the CoOP (air-sea gas exchange) program of NSF. The first CoOP field experiment took place in conjunction with the MBL West Coast Experiment in 1995.
The objective of our CoOP program is to study the effect of physical and chemical processes near the air-sea interface on the air-sea gas exchange in coastal waters.

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Figure 2. Frequency spectrum (top) and frequency-wavenumber spectrum (bottom) of surface waves from MBL West Coast. Along-wind direction. Solid line, dispersion relation; red dots, location of spectral peak at a given frequency.